

# 1.0 Introduction

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## 1.1 Background

The South Florida Water Management District (District) is conducting research focused on potential advanced treatment technologies to support the reduction of phosphorous loads in surface waters entering the remaining Everglades. Particular focus is being placed on the treatment of excess surface waters from the Everglades Agricultural Area (EAA) as well as Lake Okeechobee water that is diverted through the primary canal system to the Lower East Coast of Florida.

Federal- and state-level Everglades restoration efforts are focused on addressing two programmatic factors: reduction of stormwater-based phosphorous (P) loading to the Water Conservation Areas (WCAs)/Everglades National Park, and promotion of sheet flow through the system. The Everglades Forever Act (EFA) mandates an interim performance standard of producing treated waters with total phosphorous (TP) concentrations of 50 parts per billion (ppb) or less. However, this may not be low enough to prevent alteration of the aquatic and wetland ecosystems downstream in the remaining Everglades; ongoing research and an anticipated formal rulemaking process will seek to define what will be the ultimate TP standard.

Examination of the basis for the proposed use of Managed Wetland Treatment Systems (MWTSs) for P removal has indicated that insufficient data presently exist to compare their technical and economic feasibility to other identified supplemental technologies (Peer Consultants and Brown and Caldwell, 1996). However, considerable data do exist regarding treatment capabilities of macrophyte-based wetland systems and the performance and operation of chemical treatment systems. For these reasons it is necessary to evaluate existing data and to conduct additional research and pilot testing of the MWTS to meet the EFA's criteria for alternative supplemental technology evaluation.

This plan for the MWTS research and demonstration project called for the design and execution of scientific and engineering research to generate valid and defensible data regarding coupling of chemical and wetland treatment systems, with specific focus on quantifiable relationships between TP removal capacity and key design parameters for a conceptual full-scale MWTS.

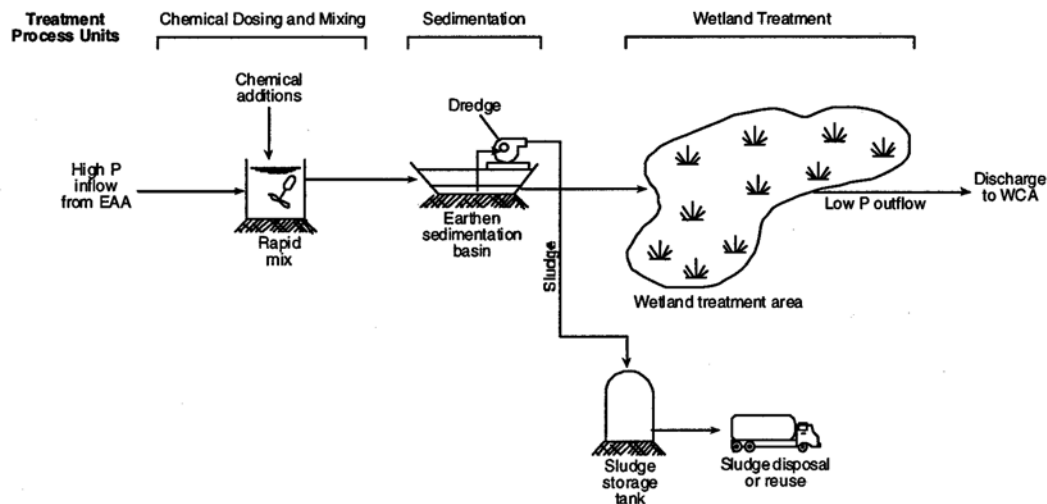
## 1.2 Treatment Process

The MWTS technology demonstration project provided an opportunity for initial testing of integrated treatment technologies for phosphorous (P) removal. Schematically depicted in Exhibit 1-1, the MWTS concept is a combination technology treatment train consisting of either two or three separate units in a series, including:

- A mixing cell for chemical additions and coagulation of TP.
- A clarifier or treatment lagoon for solids contact, sedimentation, and storage/retention of precipitated TP.
- A wetland cell for final sedimentation, polishing, and ionic conditioning.

## EXHIBIT 1-1

### Schematic of Managed Wetlands Treatment System



Ionic reconditioning in the wetland component of the MWTS is presumed to be advisable to maximize the chances that the final outflow from the overall MWTS system is marsh ready (i.e., will comply with the current narrative standard for nutrients of “causing no imbalance to the natural flora and fauna” [Chapter 302, Florida Administrative Code]).

This concept was realized in the Everglades Nutrient Removal Project Site Experimental Cells areas at a pilot scale using chemical treatment plants with sludge settling tanks connected to small wetland cells.

## 1.3 Research Objectives

The purpose of this project was to test the ability of an MWTS to achieve EFA goals. This was a research, demonstration, and optimization project with the objectives of obtaining nutrient removal performance data and operational experience sufficient to:

- Perform a preliminary evaluation of the technical and environmental feasibility of using MWTS for P removal at either basin or farm scales.
- Compare this technology with others under consideration.
- Provide design recommendations for a full-scale MWTS.

In concept, a full-scale MWTS must be able to consistently reduce water column TP concentrations to the ultimate TP target by precipitation and adsorption followed by solids storage/retention in treatment basins. Effluent from this full-scale treatment unit would be delivered to a receiving wetland to complete phosphorous polishing and accomplish ionic stabilization to ensure final effluent marsh readiness. The wetland component of the MWTS may be either a constructed system or a natural one, depending on whether the technology is applied at the on-farm or sub-basin/basin level.

The MWTS testing addressed three general research objectives:

1. Achieving TP concentration of 10 ppb or less by chemical treatment. Characterize the relationships between the efficiency of TP removal in an MWTS and key design parameters, such as influent TP concentration and mass-loading, coagulant selection and concentration, polymer selection and concentration, hydraulic loading rate, solids contact system, solids retention time (SRT), solids handling and disposal, effects of solids aging on long-term phosphorous removal, and wetland configuration and optimization.
2. Determining the effective range of treatment overflow rates and SRTs for chemically treated EAA runoff with selected P concentrations and loads that achieves a target P removal efficiency for the chemical treatment component of the MWTS. Quantifying solids overflow from the chemical treatment unit into the wetland unit, and from the wetland to downstream waters. Assessing the rate and spatial distribution of metal solids deposition in the wetland.
3. Using the paired watershed design, evaluate whether effluent from an MWTS that receives chemically treated water differs qualitatively from effluent from constructed wetlands that only receive EAA runoff water. Identifying whether the effluent from a MWTS is marsh ready, as defined by Florida Department of Environmental Protection (FDEP) procedures (*Phase 1 Procedures for Evaluating the Potential for Effects to Everglades from Discharge from Pilot Testing for Supplemental Technologies*, 1996). Assessing the ability of the wetland unit to provide ionic conditioning at relatively high hydraulic loading rates.

There were two phases of study for this MWTS demonstration, summarized as follows.

- **Phase 1** focused on technology evaluation through field-scale experiments to be performed at the north and south Everglades Nutrient Removal (ENR) project test cell complexes. The ENR testing utilized a paired watershed experimental design, consisting of two periods of study: a 7-month baseline calibration period followed by a 9- to 10-month evaluation of poly-aluminum chloride and ferric chloride treatments. Three cells in the north were used to evaluate MWTS technology by using higher phosphorous concentration waters, comparable to those that are present in drainage from EAA sugar cane or vegetable farms, or from citrus groves being developed in portions of the western basins (west of the EAA proper). Two additional cells in the south were used to evaluate this technology using PACL but not FeCl with lower phosphorous source waters, comparable to those that might be derived from the discharge outlets from cattail-based Stormwater Treatment Areas (STAs) under development during Phase I of the Everglades Construction Program (ECP).
- **Phase 2** of the MWTS project was to be conducted contingent upon the successful completion of permitting by the District and the Seminole Tribe. Phase 2 was to consist of an additional field-scale demonstration by using an alternative receiving wetland system, a hydrologically altered natural cypress wetland at the Seminole Reservation. Twelve months of testing were planned under two treatment regimes: 6 months without chemical treatment followed by 6 months with chemical phosphorous removal to a low level of 10 ppb. These tests were to be conducted at a larger scale than can be accomplished in the ENR test cells, and would also be designed to address some basic scale-up field issues, such as constructability, seepage management, and potential impacts to natural receiving wetlands. Because of the geographic separation between the Phase 1 and Phase 2 study sites and the differences in agricultural drainage involved,

the information generated would allow direct evaluation of technology application to clean up western basin drainages into the western part of WCA 3A. Phase 2 plans included cooperative in-kind participation by the Seminole Tribe.

The Seminole Tribe ultimately decided not to continue the cooperative relationship with the District on this project, and the second phase of the project was not realized.

## 1.4 Testing Philosophy

During the January 1999 Scientific Advisory Council (SAC) workshop, the SAC members, project team members, and other participants discussed and gradually defined the testing philosophy of the managed wetlands supplemental technology evaluation. This dialogue ultimately confirmed the defining vision of MWTS as a unique and distinct supplemental technology.

Without a defined focus, the MWTS concept offers diverse avenues for investigation. Realizing this conflict, SAC workshop participants identified two clear, yet divergent, options that best captured the unique features of the MWTS. The options provided two differing testing philosophies for framing the MWTS evaluation.

**Philosophy 1** – Use chemical treatment to provide target TP levels of 10 ppb or less. Rely on the wetland system for ionic conditioning to protect downstream waters and the integrity of biological communities, and to capture solids overflow from chemical system.

**Philosophy 2** – Use chemical treatment to achieve moderate TP reductions (20 to 40 ppb). Rely on the wetland system to provide multiple functions including residual TP removal down to the target 10 ppb level, capture of solids overflow, and ionic conditioning.

As a backdrop to establishing the MWTS testing philosophy, participants discussed the historical development of the supplemental technology program. The goal was to contrast managed wetlands with several other related supplemental technologies, in particular low intensity chemical dosing (LICD) and chemical treatment and solids separation (CT/SS). Based on the SAC review, the unique and defining features of MWTS were characterized by the following elements:

- Higher treatment target for chemically mediated TP removals as compared to the original concept for LICD
- Quantification and characterization of solids produced by chemical additions
- Physical and operational separation of the chemical and wetland treatment unit processes
- Optimized SRT in the chemical treatment process
- Optimization of TP removals through both precipitation and absorption
- Application of wetland treatment process for ionic conditioning of chemically treated waters, storage and processing of residual solids, and residual phosphorous removal
- Demonstration of wetland restoration options by water level augmentation of hydrologically altered wetlands

## 1.5 Key Technical and Operational Issues

This research plan focused on the following technical and operational issues:

- Characterization of TP removal efficiency in an MWTS
- Evaluation of chemical treatment variables (selection of coagulants and polymer, cost versus removal efficiency)
- Characterization of the nature and efficiency of ionic conditioning in the wetland component
- Quantification and characterization of solids from chemical treatment
- Chemical and wetland system design and operation

These key issues are discussed below.

### 1.5.1 Characterization of TP Removal Efficiency in an MWTS

The long-term average water column TP achievable in an MWTS discharge should be determined in a manner that considers the multiple factors affecting treatment performance (i.e., effects of constituent and hydraulic loading rates, seasonal variation in inflow amounts, flow velocity, inlet TP concentration, background TP levels in the wetland system, internal flow dynamics in the wetland, outlet structure design, seasonal patterns, climatic events such as droughts and hurricanes, and stochastic variability).

In the initial draft research plan, prepared for the first SAC meeting in January 1999, wetland depth was proposed as an experimental variable; however, based on the recommendation of the SAC at that meeting, a single wetland target operating depth was recommended for all ENR testing.

Relationships were characterized between the efficiency of TP removal in an MWTS and several key design parameters, such as influent TP concentration and mass-loading, internal system phosphorous accretion and effluent phosphorous concentration, coagulant selection and concentration, polymer selection and concentration, solids contact system, SRT, hydraulic loading rate (HLR), solids handling and disposal, solids aging, and wetland configuration.

### 1.5.2 Determination of Chemical Treatment Variables

The range of effective treatment overflow rates and SRTs was determined for chemically treated EAA runoff with ambient P concentrations and loads, which achieves an optimum P removal efficiency for the chemical treatment component of the MWTS. As defined in the MWTS testing philosophy, target outflow TP concentration from the chemical treatment unit to the wetland unit was 10 ppb. A combination of laboratory prescreening and then pilot testing was used to optimize the chemical treatment system. Laboratory testing was initially focused on setting dosing rates for alum and ferric chloride, on selection of polymer, and on evaluation of floc characteristics and solids behavior, the maximum overflow rate, and the effect of solids settling on SRT.

After concerns were expressed about the potential effects of adding sulfate to the system poly-aluminum chloride was tested and then used in place of alum (aluminum sulfate).

### **1.5.3 Characterization of Nature and Efficiency of Ionic Conditioning in a Wetland**

The MWTS testing philosophy that the SAC adopted defines the primary wetland treatment function as ameliorating water quality differences between waters chemically treated for P removal and ambient conditions of the downstream Everglades receiving system. The methods for accomplishing this are detailed in FDEP's Phase 1 protocols. In the ENR testing, the relationship between the efficiency of ionic conditioning and HLR was evaluated for a target rate of 10 centimeters per day (cm/d).

The District had concerns about the downstream effects of the MWTS technology, particularly regarding constituent mobilization as a byproduct of operating the system. Other concerns included the ultimate fate and handling of residual solids and the ionic conditioning of MWTS-treated waters in terms of the potential to create undesirable changes to natural Everglades biota. The MWTS-treated waters needed to have very low residual concentrations of metallic coagulants and to generate a natural ionic content to minimize the potential to create an imbalance in natural Everglades biota.

### **1.5.4 Management and Fate of Solids**

The currently defined MWTS concept, its unique characteristics as a supplemental technology, and its adopted testing philosophy all placed a critical importance on optimizing TP removal through both precipitation and the absorptive capacity of metal hydroxide solids. Therefore, the life-cycle of the solids complex in the chemical treatment process was assessed for TP removal targets, storage, management, removal and disposal, aging effects, solids overflow to wetland, depositional rates and spatial patterns within the wetland, and downstream export from the wetland.

## **1.6 MWTS Experimental Design**

A paired watershed design was selected as the theoretical model for the MWTS project. The design included two sets of three model watersheds, with the two sets separated geographically and receiving inflow water from different sources and consequently with different inflow phosphorous concentrations. Five of the six model watersheds were used in the final analyses. Chemical treatments were applied to three of the six cells, and two remained untreated as control units, and one, while sampled for much of the project period, was not included in the final analysis. The treatment cells were monitored for seven months prior to application of chemical treatment, followed by between 9 and 11 months of monitoring (depending on the watershed) during experimental treatment.

The two treatment effects that were tested included:

- Total Phosphorous Loading: two treatment levels including high (50 to 200 ppb) and low (20 to 50 ppb) levels of phosphorous concentration, one in each block of cells;
- Chemical Type: two treatment levels including a ferric metal salt and aluminum metal salt and a control with no chemical added.

In addition, subsampling of the test cells provided information on the effects of a target hydraulic loading rate (HLR) of 10 cm/d. This was performed by subsampling each experimental unit in three locations along the longitudinal axis of each test cell. Since all of the test cells had the same treatments of hydraulic load, this factor was not considered an

experimental treatment, but its effect can be studied using statistical techniques. The analysis of HLR will be discussed in the section on statistical methods. It would have been preferable to test the effect of hydraulic loading by setting up several test cells with physically different hydraulic loads. The power of the statistical analysis to detect different effects caused by HLR using subsamples is not as great as what would be provided by independent experimental observations.

The District allotted six treatment wetland cells to the MWTS experiment. One block of three cells was located in the north unit of the ENR project site, and the second block of three cells was located in the south unit. In northern test cells (NTCs), effluent of the treatment of ferrous salt was applied to one cell, effluent of the treatment of aluminum salt was applied to a second cell, and the third cell received water directly from the STA with no treatment. At the block of southern test cells (STCs) only the aluminum treatment was applied. Since the water sources to the two blocks were different, the phosphorous levels were also different, with expected mean TP concentration as described above. A summary of the treatments received by each of the six cells is presented in Exhibit 1-2. The experimental units were monitored for a treatment period of approximately 10 months. Water quality samples were collected at intervals of 1 to 2 weeks, depending on the parameter, as described in the section on sampling protocol. This provided a total of 20 to 40 repeated measurements on each test cell to determine the effects of the treatments.

**EXHIBIT 1-2**  
Experimental Treatments

Treatment	P-loading	Chemical Type
1	H	Fe
2	H	Al
3	H	None
4	L	None
5	L	Al
6	L	None

H = High

L = Low

Al = Aluminum salt

Fe = Iron salt

None = Control unit, no chemical treatment

There was no experimental replication among the treatments. However, initial monitoring of all six experimental units without chemical treatment allowed determination of the relationship between the treatment cells and control cells for use in a paired watershed design analysis, such as used by the U.S. Environmental Protection Agency (USEPA) for nonpoint source pollution studies (USEPA, 1993). Following the initial seven-month monitoring period without treatment, known as the calibration period, the treatments were applied for 10 months to study the response over time. This allowed researchers to characterize within cell variation, and to determine the average treatment effect that can be sustained by the treatment processes. The procedure outlined under the paired watershed study design used statistical analysis of covariance to show how the treatment effect differed from what would normally occur without treatment as predicted by the control cell

during the treatment period. This resulted in a total of 17 months of monitoring of the test cells. The method of analysis of the paired watershed design is described in detail in Section 7 on statistical methods.

Prior to the application of experimental treatments in the six cells, the six test cells were monitored for 7 months during the calibration period. The sampling schedule that was applied during the calibration period was the same as the sampling schedule in operation during the treatment period. This resulted in a total of 14 to 28 repeated measurements on each cell for purposes of calibrating the treatment cells to the control cells.

Since the two blocks of cells are in separate locations, there were two different control cells, and this configuration was similar to having two separate sets of paired watersheds. As a result, it was necessary to perform two separate calibration exercises during the final analysis.

In order to appropriately simplify the statistical analysis, after the control cell in the low P-loading treatment cell set had been identified, only a single control cell was used there, rather than the two cells initially designated as such.

The main treatment effect of chemical precipitation occurred in a controlled, physical process. The final treatment polished the effluent by passing the effluent through treatment wetland cells containing cattails and other submerged aquatic vegetation that occurs naturally in the Everglades. The wetlands treatment system was expected to produce an effluent that had an ionic and biological condition similar to water in the Everglades, downstream. Statistical tests were performed to determine whether the ionic and biological condition of the effluent was similar to that in the Everglades. The analysis is presented in Section 7 on statistical methods.

Although the treatment wetlands are constructed and therefore artificial, they have many similarities to natural systems, and the final polishing treatment was performed by natural plant communities. As such, the efficiency of the plant communities in the treatment wetlands varied under the influence of the stochastic effects of weather and climate. Since these factors can not be controlled experimentally, the statistical analysis must account for, and control for, their effects. This allowed the determination of the effects of the chemical treatments that might otherwise be masked by the natural variation caused by the stochastic effects of weather and climate. The accounting and statistical control of stochastic effects is a key component of the paired watershed analysis (USEPA, 1993), and is described in the section on statistical methods.

The similarities of the treatment wetlands to natural systems and their exposure to natural, stochastic elements made these systems similar to natural watersheds. Consequently, methods for their analysis were borrowed from the great body of literature on analysis of water quality treatment effects on the scale of watersheds. The use of paired watershed analysis was first developed to study the effects of silviculture on water quality in watersheds, and has been used for over 40 years (Clausen et al., 1996).

## **1.7 MWTS Scientific Advisory Council (SAC)**

An MWTS Scientific Advisory Council convened to provide review of the research plan for experimental design, data collection, data analysis, and interpretation of results. The name



of the group was changed from Scientific Review Panel (SRP) to SAC to avoid confusion with the acronym for Soluble Reactive Phosphorous, used frequently in this document.

Participants at the first SAC meeting, with the exception of the project consultants, included the following:

- **SAC Members**

- Dr. Robert Knight, Consultant, Wetland Solutions, Inc.
- Dr. Luke Mulford, P.E., Consultant, University of Central Florida, Orlando, Florida
- Dr. K. Ramesh Reddy, Consultant, University of Florida, Gainesville, Florida
- Dr. Gary Amy, P.E., Consultant, University of Colorado, Boulder, Colorado
- Dr. Taufiqul Aziz, Florida Department of Environmental Protection

- **District Staff**

- Dr. Jana Newman
- Dr. Susan Gray
- Dr. Mike Chimney
- Lori Wenkert
- Drew Campbell
- Jose Lopez, P.E.
- Dr. Jennifer George

- **Seminole Tribe**

- Patty Lodge
- Dr. Bill Dunson

- **Other**

- Dr. Robert Kadlec, P.E., WMS, Chelsea, Michigan (representing U.S. Department of Interior)
- Dr. Glenn Daigger, P.E. (CH2M HILL)

During the course of the project, the SAC and other participants of the first meeting were consulted both formally (during subsequent meetings) and informally as part of the project process.

In addition to the current District staff, Greg Coffelt, a former District staff member was the District's project manager from the project inception until approximately February 2001. The MWTS evaluation was authorized in November 1998. The objective of this research (Phase I) was to identify preferred technologies that should be designed and implemented full-scale to optimize treatment performance of the cattail-based STA during Phase II of the State's ECP.

Calibration period sampling at the ENR Test Cells took place from the first week of July 1999 through the beginning of February 2000. During the calibration period, untreated source water was being discharged to both the North and South Test Cells.

Chemical treatment of source water with either ferric chloride or a poly-aluminum chloride (PACL) compound was instituted during the third quarter in three cells, two treatments in the north test cell site and one treatment in the south test cell site. An additional cell in each location served as a control. The chemical treatment period lasted for more than 9 months.